CORRIDOR: A Routine for Estimating; the Initial Wave Front Resulting from High Temperature Fire Exposure to a Corridor

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Building and Fire Research Laboratory
Gaithersburg, MD 20899

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ABSTRACT

A first order model and computer program implementing previously developed procedures for estimating the speed, depth, and temperature of a fire produced gravity wave front in a corridor have been developed. The program has been incorporated into FPETOOL and adjustments made to accommodated fires that occur in the corridor or in a room adjacent to the corridor. Comparisons to test results are presented and show reasonable correlation. A users' guide is included.

Key words: corridor flow; gravity wave; fire modeling; heat loss; hazard; flashover

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NOTATIONS

B_0	=	A variable used in calculating velocity of the smoke front
c_p	=	Specific heat of air (1.0035 kJ/kg-K)
Dt	=	Depth of smoke front at time t (m)
e	=	Emissivity
h_c	=	Convective portion of heat loss coefficient (W/m^2-K)
h_l	=	Heat loss coefficient (W/m^2-K)
h_r	=	Radiation portion of heat loss coefficient (W/m^2-K)
K_0	=	A constant used in other equations
K_e	=	A calculated variable used in equation 12
m_c	=	Total rate of mass flow into corridor (g/s)
m_e	=	Mass entrained in smoke flow from room into corridor (g)
m_f	=	Mass flow from fire room (g/s)
ρ_{amb}	=	Density of air air T_{amb} (1178 g/m^3))
q_f	=	Energy flow from fire room to corridor (kW)
S_B	=	Stefan-Boltzman constant (5.67 10^{-8} W/m^2-K)
t	=	Time from start of corridor flow (s)
T_{amb}	=	Ambient temperature (assumed to be 294 K)
T_{avg}	=	Average temperature of smoke wave (K)
T_s	=	Temperature of smoke leaving room (K)
Tx	=	Temperature at position X (K)
Tx_n	=	Temperature at point n (K)
V_0	=	Velocity of smoke in corridor at room of origin (m/s)
V_f	=	Volume flow from room (cms)
Vf_{i-1}	=	Velocity of smoke front at previous time step (m/s)
Vf_i	=	Velocity of smoke front at present time step (m/s)
W_c	=	The width of the corridor (m)
x	=	A distance from the room of origin (m)
Xf_{i-1}	=	Position of smoke at start of time step i (m from point of origin of wave)
Xf_i	=	Position of smoke front at end of time step i (m from point of origin of wave)
z	=	Entrainment length (m)

1. INTRODUCTION

This report describes an additional module added to the FPETOOL[1] collection. The new module is entitled CORRIDOR and is accessed from the main menu of FPETOOL. CORRIDOR is a first order model useful in approximating the initial flow conditions from **a** steady state fire condition such as usually occurs following flashover. The results are an approximation and should be treated as such. Section 3 of this report provides information on the comparison **of** the results obtained from CORRIDOR and experimential data. Users should review that section to assist in determining the appropriateness of applying CORRIDOR to problem solutions. CORRIDOR is included in FPETOOL starting with Version 3.1. CORRIDOR predicts the initial flow of a wave front generated by a fire either in the corridor or in a room adjacent to the corridor. The routine predicts the rate of travel, the position of the wave front at any time, the depth of the wave front, and the longitudinal temperature profile of the hot gas behind the wave front. The module calculations end when the wave front reaches the remote terminus of the corridor as prescribed by the user. CORRIDOR is designed to evaluate conditions with a steady rate of smoke flow from the generating source, smoke flow being defined in terms of temperature and quantity. Its primary use is focussed on post-flashover or other fire conditions that have reached essentially a steady state.

The computations in the CORRIDOR routine are based on the review of fire induced flows in corridors conducted by Steckler[2]. Many of the equations used are taken directly from Steckler's summary. In this, Steckler reviewed the prior work of Hinkley[3], Emmons[4], Zukowski and Kubota[5], and Heskestad and Hill[6]. Steckler, in the introduction to his report, states "Corridors often serve as conduits for transporting life threatening combustion products from localized fires to other areas of **a** building. For example, combustion products from a fire developing in an office often pass through a doorway or other penetration to an adjacent corridor where they establish a buoyancy driven flow beneath the ceiling. Figure 1 illustrates the basic features of this flow as outlined by Zukowski. Initially, a "forward" gravity current of heated gas propagates away from the fire source along the ceiling of the corridor. Since buoyancy drives the flow, any loss of buoyancy due to heat transfer from the upper **gas** reduces the velocity of the front and also increases its depth. Upon striking the end wall, the flow reverses and forms a "return" current or wave beneath the existing layer. Eventually the wave disappears and the layer tends to fill (thicken) uniformly."

The initial forward wave discussed in the preceding paragraph is the product calculated by CORRIDOR. Review of the available test data also indicates that the return wave discussed above will be of approximately the same thickness and traverse time as the forward wave at a temperature approximately that of the wave front when it reached the terminal end of its flow (struck the far end of the corridor).

The conditions modeled by CORRIDOR also assume that the corridor is closed (as would be expected of an internal corridor in a building). If the corridor is vented at its terminus, it **is** probable that the forward wave front will respond in a manner similar to that in **a** closed

corridor but that the return wave will either be non-existent or greatly changed depending on the actual conditions at the vent end of the corridor. In addition the air flow from the opening to the fire source coursing in the opposite direction and below the smoke wave can cause turbulence at the lower face of the forward wave causing a mixing and deepening of the wave along its lower boundary. Such an action was reported by Heselden and Hinkley [10] and reported as a zone of lower density smoke between the main body of the smoke wave and the main body of the in-flowing air during their tests involving an 8 MW fire source.

As pointed out by Steckler, it is important to note that the scope of CORRIDOR addresses buoyantly driven non-reacting gravity currents and does not address conditions where there is an additional pressure developed by HVAC, stack effect, building collapse, wind, or other causes. CORRIDOR assumes that there is no significant combustion within the wave. For this to be true, the combustion must either be completed within the exposing room or the immediate vicinity of a fire within a corridor. This will be true if the total combustible mass released is not sufficient for combustion beyond the immediate area of the fire or if the oxygen content in the wave and/or other entraining gases is insufficient to permit complete combustion. This latter case would normally be expected in the gases released from a flashed over room into an adjacent comdor where the ceiling height in the corridor is a relatively short distance above the soffit **of** the opening where the gases are being released. CORRIDOR is not appropriate for situations where a high corridor ceiling would allow the development of a plume that would entrain sufficient air to assure further combustion of products from a flashed over room. In such case it is expected that the corridor filling may be better predicted by one of the standard compartment fire models such **as** FIRE SIMULATOR also contained in the FPETOOL [1] collection. CORRIDOR warns the user when this case occurs.

2. ALGORITHM

The primary routines in CORRIDOR are functions of the mass, temperature, and energy in the established wave in the corridor. The procedure in the program expects that the fire may initiate in a room open to the corridor. The algorithm, therefore, is two step. In the first step, the initial conditions at the origin of the wave front are determined based on inputs that the user would obtain from the execution of FIRE SIMULATOR or a similar room fire model.

The second phase is the calculation of the position of the smoke front, the depth **of** the smoke wave, and the temperature distribution in the smoke wave at any time interval. In the second phase, the calculations step through the process on one second intervals determining the position of the front and the distribution of temperature at 0.1 m increments.

2.1 Mass Flow from Fire Room

FIRE SIMULATOR reports the flow from a room fire in terms of volumetric flow and temperature of the flowing gases. This is converted to mass flow by Equation 1.

$$m_f = V_f(T_{amb} / T_s)\rho_{amb} \tag{1}$$

2.2 Energy Flow from the Room

CORRIDOR assumes that there will be no combustion in the out-flowing gases. It therefore ignores the presence of any unburned fuel in these gases. The energy in the gases is therefore the enthalpy resulting from the temperature difference of the out-flowing mass calculated by Equation **2.**

$$q_f = m_f c_p(T_s - T_{amb}) \tag{2}$$

2.3 Mass Entrained into Smoke Flow from Room

If the smoke flow entering the corridor enters through a doorway that is either narrower than the corridor or has a height lower than the corridor, smoke will rise as it is discharged from the room entraining air from the corridor, thereby increasing the mass of the smoke body with the resultant impacts on depth, velocity, and temperature of the wave. An estimate of the amount of this entrainment is made using the same Heskestad[7] equation as used in FIRE SIMULATOR analysis of the impact of entrainment. In CORRIDOR, however, the equation **is** expressed as a point source equation with the base of the entrainment plume at the lowest level of smoke emitting from the door of the exposing room. The form used is expressed in Equation **3.** This entrainment equation is known to be a general approximation as there is no simple exact expression for the entrainment in such **a** flow, (Baum[8]). Because of this, a provision **is** included to allow the user to proportionately increase or decrease the total entrainment for either parametric studies or in view of improved data on the actual entrainment involved.

$$m_e = 71 q_f^{113} z^{513} \tag{3}$$

The mass flow in the corridor is then assumed to be the sum of the mass emitted from the exposing room plus that entrained after it leaves the room. The initial smoke depth, mass rate, velocity, and temperature of the wave are then proportionately adjusted to reflect the increased mass of corridor temperature air entrained into the flow. CORRIDOR always assumes that air entrained from the corridor is at ambient temperatures. CORRIDOR assumes a room temperature of 21°C (70°F). In those cases where the fire initiates in the corridor or where the size of the opening equals the height of the corridor and the width of the opening equals or exceeds the width of the corridor, no entrainment takes place. Further, if the amount **of** entrainment exceeds the mass flow from the room by a factor of two or greater, a warning **is** presented to the user that the results are beyond the known capabilities of CORRIDOR. It **is**

possible that such a plume would result in a condition similar to simple filling model such as FIRE SIMULATOR in the FPETOOL collection [13. Parametric studies with CORRIDOR, however, indicate that it is undesirable to use this routine under such conditions.

If the user enters values for the concentration of carbon monoxide, carbon dioxide, and oxygen in the out-flowing gases, they are similarly adjusted by the same proportion assuming that the corridor air contains 21% oxygen, 0% carbon monoxide, and 0% carbon dioxide.

2.4 Position of Smoke Front

The position of the smoke front is set to zero at the beginning of each run. The zero position is the door to the room from which the smoke is emitting or the point of origin if the fire is in the corridor. The advance of the smoke is then calculated on 1 second time steps using Equation **4.** This equation assumes that the average velocity during any one second time step is the mean of the velocity at the start of that time step and the velocity at the end of that time step. Velocity being calculated as described in 2.6 below.

$$Xf_i = Xf_{i-1} + (Vf_i + Vf_{i-1})/2 \qquad (4)$$

2.5 Heat Loss from Smoke Wave

An effective heat loss coefficient in terms of W/m^2-K is developed **as a** combination of a convected heat loss coefficient and radiant heat loss coefficient (Equation *5)*. The convected heat loss coefficient is a user-input with a default value of $20\ W/m^2$-K and an expected range of 5-50 W/m^2-K.

$$h_l = h_r + h_c \qquad (5)$$

The radiant portion of the heat loss coefficient is separately calculated based on the average temperature in the smoke front at each time step. Using Equation 6b which is derived **from** Equation 6a. The value of emissivity is a user input having a default value of 1.0. The expression in the numerator of Equation 6a is an expression of the average radiant heat **loss per**

unit area from the smoke wave. The term in the denominator is the average temperature rise. The equation produces an average heat loss coefficient per unit area per degree temperature rise. Radiant heat loss is an important factor in any situation where the average temperature in the wave front is high. For example the radiant portion of the heat loss coefficient is approximately 50 W/m^2-K if the average temperature is 600 "C (1112 °F), 35 W/m^2-K at 500 "C (932 °F), 23 W/m^2-K at 400 "C (752 °F), 14 W/m^2-K at 300 "C (572 °F) and **8** W/m^2-K at 200 "C (392 °F). By comparison the convective heat loss portion **is** a user selected input usually in the 10 to 30 W/m^2-K range. **As** a result the radiant heat losses are a significant factor near the point of origin of a hot fire source but decrease in impact with distance or lower temperature fire sources.

$$h_r = eS_B (T_{avg}^4 - T_{amb}^4) / (T_{avg} - T_{amb}) \tag{6a}$$

$$h_r = eS_B(T_{avg}^3 + T_{avg}^2 T_{amb} + T_{avg} T_{amb}^2 - 3T_{amb}^3) \tag{6b}$$

Equation 6b is the algebraic extension of Extension 6a except that the last term ($-3T_{amb}^3$) is used instead of the actual algebraic term ($+T_{amb}^3$). This change has negligible effect on the radiation portion of the heat loss coefficient and avoids the anomaly that would occur as the average temperature approached the ambient temperature.

The calculation of the radiant portion of the loss coefficient involves the average temperature of the smoke wave. The smoke temperature is calculated as described in Section **2.7,** below, at 0.1 m intervals along the smoke front and is recalculated at each one second time step of the program. **A** integrated average is developed as expressed in Equation 7. T(x) is the expression developed by equation 11.

$$= \underline{\qquad} \tag{7}$$

2.6 Velocity of the Wave Front

Velocity of the wave front is developed using Equations 7 and 10 of Steckler's report [2]. Equation 7 from Steckler's report is shown as Equation **8,** below. This develops a constant used in calculating both the velocity and the depth of the smoke wave. It is an expression related to the impact of heat loss per meter of length of the corridor.

$$K_0 = h_1 W_c/(3mc_p) \tag{8}$$

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The velocity is then expressed in Equation 9.

$$Vf_i = V_0\{T_{amb}/T_s \exp(-3K_0Xf_i) + B_0\}^{1/3} \tag{9}$$

Where:

$$B_0 = [(T_s - T_{amb})/T_s] \exp(-6K_0Xf_i) \tag{10}$$

This results in an exponential decay in velocity readjusted at each 1 second time step for any change in the heat loss coefficient and the advance of the smoke front. The use of exponential decay equations as recommended by Steckler is an essential simplifying element in CORRIDOR and a reason that in its current form CORRIDOR is restricted to estimation of conditions from a steady state fire source.

2.7 Temperature Distribution Within the Smoke Wave

The temperature distribution within the smoke wave is calculated at each time step for each 0.1 meter increment along the length of the smoke wave. Equation 9 of Steckler's report [2] is used. Again, an exponential decay occurs as an impact of heat loss per unit length of the corridor and the distance along the wave, the heat loss factor being adjusted for each one second time step. The temperature is calculated for 0.1 m increments along the length of the wave. The Equation used is shown as Equation 11 in this report.

$$T(x) = T_{amb} + (T_s - T_{amb})\exp(-3K_0X) \tag{11}$$

2.8 Depth of Smoke Wave

The depth of the smoke wave is calculated using Equations 11 and 11A of the Steckler report [2]. These are expressed as Equations 12 and 13 in this report.

$$Dt = m_ctT_s/(T_{amb}\rho_{amb}K_eW_c) \tag{12}$$

Where:

$$K_e = Xf_i + 1/(3K_0)\ln\{(T_{amb}/T_s) + [1 - (T_{amb}/T_s)]\exp(-3K_0Xf_i)\} \tag{13}$$

The approach used is based on Steckler's analysis of Hinkley's equations for a hot gas solution [9]. As noted by Steckler, the hot gas solution will also serve for cooler gases. One major deviation from Steckler's recommendations was made in the calculation of the position of the smoke front. The approach used in Equation 4 above is felt to constitute a reasonable and rational approximation that avoids the necessity of an iterative solution.

2.9 Estimating Gas Concentrations.

CORRIDOR uses the results of the mass entrained into the smoke (equation **3)** to determine the portion of the smoke emitted from the source versus that entrained from the lower portion of the corridor. It is assumed that the air entrained contains 21% (by volume) oxygen and no carbon monoxide or carbon dioxide. The user inputs the concentrations of these gases in the emitted smoke. CORRIDOR then adjusts the concentration in the wave by the rate of dilution of the emitted smoke with corridor air.

3. COMPARISON OF CORRIDOR TO EXPERIMENTAL DATA

3.1 Data sources.

Three sources of experimental data useful in testing CORRIDOR were found as follows:

a.   Heselden and Hinkley[10]

This work was conducted by the UK Fire Research Station. In this series of tests open fires estimated at 2 MW and 8 MW were built in an unused railroad tunnel approximately 5 m high **x** 6 m wide **x** several hundred meters long. The fire was located approximately 180 m from one end. The tunnel was built of brick and had an arched ceiling. Measurements were made with several thermocouple trees and observers visually reporting the position and depth of the smoke front. The tunnel was open at both ends and as such no return wave was generated. The authors report that with the 8 MW fire, there was a significant inflow of air supplying the fire that impacted on the smoke wave, causing some turbulence along the bottom of the smoke wave producing an additional depth believed to be composed of a mixture of the out-flowing gases and the in-flowing air.

b.   Heskestad and Hill [6]

This NIST* sponsored project was conducted at Factory Mutual Research Corporation test facilities at West Glocester, RI. A series of sixty tests with varying parameters were run in an 18.89 m long x 2.4 m wide (**2.44** m high) corridor with a burn room located off the side of the corridor near one end. Readings were taken by a number of instruments. Most important to this analysis were three vertical thermocouple trees located at varying distances along the corridor and one thermocouple tree located in the burn room. A fire was produced by a sandbox burner fed with propane gas in the burn room. For the purposes of comparing the results of this work to CORRIDOR, test 2 involving a 56 kW fire and test 16 involving a 522 kW fire were found most suitable and used for comparison with results of the model.

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* **At** the time this project was conducted the National Institute of Standards and Technology **(NIST)** was known **as** the National Bureau of Standards (NBS)

c.   Stroup and Madrzykowski [11].

This General Services Administration project was conducted at the NIST facilities in Gaithersburg, MD. Four fire tests were conducted with a fire ignited in a bum room abutting the end of a corridor 12.8 m long x 2.4 m wide x 2.4 m high. There was an opening between the burn room and the corridor 1.52 m high and 4.6 m wide. There was also an opening from the burn room to the exterior 1.52 m high and 0.76 m wide. There were thermocouple trees in the burn room, immediately outside the burn room and the corridor, and at 3.05 m intervals down the length of the corridor. The fire was produced by burning wood cribs. The report indicates heat release rates that peaked at between 2 and 2.5 MW within approximately 150 seconds of ignition and contained energy release rates in the range of approximately 1.25 to 2.0 MW for a period of over 500 seconds.

3.2 Approach Used to Compare Test Data to CORRIDOR Output.

To the maximum extent available, data produced by the tests was used as input to the CORRIDOR model. Wherever such data were not available, the routine FIRE SIMULATOR in FPETOOL [1] was used to produce the missing data required by CORRIDOR. In general, almost all of the data except the mass or volume flow from the fire into the corridor was available. In all cases, FIRE SIMULATOR was used to produce an estimate of that flow. In the case of the Hinkley and Heselden experiments, where the flow extended in both directions, the mass and flow rates were divided in half and the calculations treated on the basis **of** a unidirectional flow. The convected heat loss coefficient is a user input. In order to obtain insight on the impact of varying this parameter, CORRIDOR was exercised at convected heat loss coefficients of 10, 20, and 30 W/m^2-K.

3.3 Results from Comparison with Heselden and Hinkley Experiments

a.   Tunnel Test 1, **2** MW Fire

Figures **2, 3,** and 4 show the comparison of the test data with the results produced by CORRIDOR**. As can be seen to the extent the test data exist, a reasonable but not perfect correlation between the test data and the predictive model exists. It also demonstrates relatively modest deviation as a result of the choice of the convective heat loss coefficient with the of 20 W/m^2 K generally but not universally giving the best results. The mass flow into the comdor was derived using FIRE SIMULATOR and assuming a room the height and width of the corridor with open doors at each end equal to the full cross section of the corridor.

Figure 2 shows two values for temperature at each of the two measurement distances in the tunnel. The test fire was located in the center of the tunnel with thermocouple located at the

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** The lines on the graphs in these and subsequent figures identified as 10, 20, and **30** indicate the results when the Convective Heat Transfer Coefficient is set at 10, 20 or **30** W/m_2-K respectively.

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same distance from the fire source in each direction from the fire. The values shown for the test reflect the fact that different temperatures were recorded for the smoke wave in one direction as opposed to the wave in the opposite direction.

b.   Tunnel Test 2, 8 MW Fire

Figures *5*, 6, and 7 show a comparison between the results of the test and the predictions **of** CORRIDOR for temperature distribution at the time the smoke wave reaches the end of the tunnel, position of the front against time, and the depth of the smoke layer. In this series of comparisons the impact of both the convective heat loss coefficient and the smoke level in the doorway were examined. Again, reasonable correlation was obtained relative to the temperature distribution and the position of the front. There is distinct variation between the predictions of the model and the reported depth of the smoke layer from the test. It is possible that this is an artifact of the test due to the turbulence at the interface caused by the flow of incoming combustion air.

3.4 Comparison with Heskestad and Hill Tests

a.   Corridor Test 2 - 56 kW Burner

Figures 8, 9, and 10 provide a similar comparison of corridor predictions verses the test data on temperature, smoke front position, and depth. **A** good correlation was obtained. In the calculation of the position of the smoke wave front, an offset of 19 seconds was inserted to recognize the filling time within the fire room before the smoke emitted from that room into the corridor. Once again, the heat transfer coefficient of 20 appears to give the best correlation. In figures 8, 9, and 10 the additional notation 1.7 or 1.8 indicate the smoke level entered in the CORRIDOR menu for the run plotted.

b.   Corridor Test 16 - 522 kW Burner

Figures 11, 12, and 13 show a similar good correlation between the module and the test data. It is not known at this time whether the peak at 3 seconds in smoke depth is real or an artifact of the calculations. As with the other cases, heat transfer coefficient of approximately 20 gave quite satisfactory results.

3.5 Correlation with Stroup and Madrzykowski Tests - Wood Cribs 2 to 2.5 MW Peak Heat Release Rates

CORRIDOR module did not successfully reproduce the test results. The very short, narrow door between the test room and the corridor was interpreted by CORRIDOR **as** producing **a** massive entrainment plume that exceeded the capabilities of the model. When this occurs **a** message appears on the screen and CORRIDOR suggests the use of FIRE SIMULATOR **as** an alternative approach in such cases. FIRE SIMULATOR was used and produced the results shown in figures **14** and 15.   The results show good correlation between FIRE SIMULATOR

and the test results for average temperature and depth. FIRE SIMULATOR, which is a uniform "filling" model, does not however estimate the temperature distribution as **a** function of position in the corridor or the velocity of any wave front. It was possible to force CORRIDOR to make a calculation by eliminating all entrainment. In which case, it gave reasonable approximation of the velocity of the smoke front and its depth but significantly under-predicted the temperatures in the second half of the corridor. The relatively high temperatures sustained in this test are surprising and different from what has been quoted in prior tests in the same corridor (Nelson[12]). Further investigation into the characteristics of smoke fronts from flashed over fires, the entrainment actually occurred in flows from the openings in such fires and the actual heat transfer in the corridors as well as the appropriate procedures to model such events appears necessary.

4. USERS' GUIDE

4.1 Accessing CORRIDOR.

CORRIDOR is reached through the selection menu of FPETOOL. To call CORRIDOR use the arrow keys to move the selection bar to the heading "CORRIDOR" and press enter. An introductory screen will occur pointing out that CORRIDOR is designed for a steady state high temperature fire exposure and that the data may be obtained from FIRE SIMULATOR for the exposing room or fire. Pressing any key will bring up the menu for CORRIDOR flow. The dimensions for height, length, width, and temperature will be in the english or metric system according to the selection made in FPETOOL SETUP. The dimensions for convective heat transfer will always be in terms of $W/m^2 K$. For each item in the menu, there is **a** brief help message available by locating the selection bar on that item and pressing the function key F1. Specific information on each of the entries follows:

4.2 Entering Data in CORRIDOR

a.   Lotus File.

As the menu initially appears, this bar will be entitled, "Lotus File Not Created." If the enter (or return) key is pressed, a screen will occur asking for a name for this file. Enter any eight character name desired and press enter. The initial bar will then display the name of the file. The extension on Lotus Files is always WK1. Once a file name has been entered the menu will reappear showing the name of the Lotus File.

If a Lotus File is named, CORRIDOR will produce a Lotus format file readable in most spread sheets. That file will provide at the time and distance intervals specified by the user a complete listing of the results obtained for position of the smoke front, depth of the smoke front, and temperature distribution through the smoke wave at each time interval specified. The format is arranged to provide for ready production of graphic output.

b.   Printer Commands

This command turns the printer on or off. As initially displayed, the printer is in the **off** position. If the user presses the enter key, the printer will be instructed to print the results and the user will be queried for a title when he instructs the program to execute. The printer command is disabled (printer instructed not to print) any time the program menu is called. This is true even if it is recalled after a run and all of the other commands are preserved.

C.   Convective Heat Transfer Coefficient

The convected heat transfer coefficient is an approximate measure of the flow of energy due to convection from a hot smoke in the corridor wave to the ceiling and portion of the walls covered by the smoke. This is a user input with a default value of $20W/m^2$-K. The actual value can vary from about 5 to $50W/m^2$-K. The value of 20 is in the approximate correct range for smooth surfaces and fires of ordinary violence, as might be expected in conditions that do not flashover. Higher numbers should be expected with any force that causes turbulence in the flowing gas. This could occur due to roughness of the surface, irregularities (recessed light fixtures, ceiling hung signs, beams, and similar partial obstructions) or an violently turbulent post flashover fire. In which case a higher heat transfer number should be used. In the investigations of test cases during the development of the model, it appeared that heat transfer coefficients ranged between 10 and $30W/m^2$-K were appropriate for most cases.

d.   SMOKE LEVEL IN OPENING

CORRIDOR is primarily designed for fires emitting from a room into a corridor. The smoke level in the opening is that level that separates the hot smoke layer flowing from the room and the inflow of gases from the corridor. Most fire growth models report this value. The position can also be estimated from test data. The smoke level is indicated by a sharp change in temperature between two thermocouple on a thermocouple tree in or near the doorway. When considering a fire in a corridor, it is also necessary to estimate this interface level. If no other data exist, it can be estimated by developing a pseudo room with openings the height and the width of the corridor and using a fire growth model such as FIRE SIMULATOR to produce an estimate of the interface.

e.   SMOKE TEMPERATURE

The smoke temperature is the temperature of the fire induced flow emitting from the exposing room. If the top of the door is lower than the ceiling of the corridor or the door width is narrower than the corridor, a plume will develop that will entrain cool air. The internal calculations within CORRIDOR account for this cooling. The value entered at this point should be the actual temperature of the out-flowing gas as measured or calculated.

f.   SMOKE FLOW

This variable calls for the volumetric smoke flow (i.e. hot gas flow) from the source at the temperature entering the corridor. CORRIDOR will convert this value to mass flow. Volume flow is used instead of mass flow since volume flow is the output currently presented in FIRE SIMULATOR printouts. If a user, however, wishes to evaluate conditions at a different temperature, it is important that he adjust the smoke flow so as to maintain the same mass **flow.** CORRIDOR is very sensitive to variations in this factor.

g.   ENTRAINMENT FACTOR

CORRIDOR internally calculates entrainment using a simple point source entrainment equation. This entry allows the user to proportionately change that entrainment. The default value of 1 will result in entrainment exactly as internally calculated in CORRIDOR. Changing **the** value to 0.5 will half the amount of entrainment internally calculated, a value of **2** will double it, a value of 0 will eliminate the entrainment. Negative values cannot be used. This adjustment factor was included because of the current state of uncertainty as to the correct plume equation to be used for such an out-flowing gas. The equation within CORRIDOR appears to give reasonable results for those situations normal to building corridor arrangements such **as** those tested by Heskestad and Hill [6]. It, however, appears to over-predict the entrainment for very high ceilings or very low openings, as in the tests by Stroup and Madrzykowski [11]. In cases where CORRIDOR predicts high entraiment the user is warned and given the opportunity of terminating the run.

h.   Concentration of Smoke Gases

The three entries CO, CO_2, and O_2, provide an opportunity for the user to enter the concentration of these gases in the exposing smoke. The default values shown are for clean air. If the user has no interest in the concentration of these gases in the smoke wave, they may remain unchanged without affecting any other calculated outputs produced by CORRIDOR. If a value is entered, CORRIDOR will adjust the value to reduce the entered concentrations for carbon monoxide and carbon dioxide and increase the concentration of oxygen proportionately to recognize the dilution of the smoke as the result of entrainment of gases from the corridor.

i.   SMOKE EMISSIVITY

CORRIDOR internally calculates the losses of energy due to radiant transfer from the hot smoke. Emissivity is a measurement of the efficiency of that transfer. In general, the blacker the smoke, the higher the emissivity. The default value of 1 is the maximum emissivity possible and represents a "black body" type of transfer. The default value of 1 is normally appropriate for fire conditions near or beyond the flashover conditions. If CORRIDOR is used to estimate conditions of lower energy fires, then a reduction in the emissivity is appropriate to recognize the lower absorbtivity and hence emmisivity of the more transparent cooler **smoke.** The results,

however, are only moderately sensitive to changes in this factor. The range of the factor is from 0 to 1.

j.   SMOKE FLOW DIRECTIONS

This entry allows the user to direct the model so that the smoke flows in one direction (**as** typified by a room at the end of a corridor) or in two directions as typified by **a** room opening in a central position in the corridor. There are only two options provided. Pressing the enter key switches between the options. When the option "SMOKE FLOWS IN TWO DIRECTIONS' is used, CORRIDOR divides the mass flow in half and adjusts the initial velocity according and tracks the one-half of the flow. If a user wishes to track both halfs, when an opening is located at **a** point other than the center of the corridor, it is suggested that the maximum distance be set for the more remote end of the corridor.

k.   OPENING HEIGHT

This is the height at the top of the opening measured from the floor. The opening involved is that from which smoke enters the corridor. If consideration is being given of a fire in **a** corridor, then the opening height is the corridor height. The opening height can never be higher than the height of the corridor.

l.   OPENING WIDTH

This is the width of the opening from which smoke enters the corridor. If the fire is in **a** corridor, this is the width of the corridor. The width of the opening into the corridor can exceed the width of the corridor. While such is not expected, there may be occasions when **a** room opening is actually wider than the exposed corridor.

m.   OPENING SILL HEIGHT

This is the height of the bottom of the opening above the floor. Enter "0" if it is a doorway. In no case can the height of the sill be greater than the smoke level in the opening.

n.   CORRIDOR HEIGHT and CORRIDOR WIDTH

The next two items cover the height and width of the corridor. These are the direct measurements of the height and width. CORRIDOR can not compensate for any changing heights or widths.

o.   MAXIMUM DISTANCE

This is the furthest distance which CORRIDOR will calculate results. CORRIDOR is arranged to stop calculations when the smoke front reaches the prescribed distance. The distance is an arbitrary input on the part of the user but would normally be expected to be the length of the corridor. CORRIDOR will calculate this distance to the nearest 0.1 meters. If an entry **is** made in feet, the computation will stop at the nearest 0.1 meters beyond that distance.

p.   DISTANCE INTERVAL

CORRIDOR calculates conditions at intervals of 0.1 meter (3.9 inches or **0.328** feet). When entries are made in metric, intervals can be set to one decimal point. When the input is given in terms of feet, CORRIDOR converts from feet to meters and adjusts to the nearest 0.1 meter. The calculation is done at this interval and converted back to feet when the module is executing in the english system. Occasionally, this will result in intervals slightly different than those requested by the user.

q.   TIME INTERVAL

TIME INTERVAL can be sent in increments of one second. The results will be displayed, entered into the Lotus file, and/or printed at the time interval selected. There is no time limit built into CORRIDOR. CORRIDOR will run until the smoke wave reaches the maximum distance specified. Or until the user presses function key F3 to terminate the run.

r.   DONE

Placing the highlight bar on "Done" indicates that the user is ready to execute the run. **If any** of the entries indicated by a diamond shape have not been completed, CORRIDOR will sound a warning tone and the entry bar will return to the top item. The program will not advance until all of the items have an entry. The program also checks for a number of incompatibility errors at this point. If conditions such as an opening height higher than the corridor height, a smoke layer higher than the opening height, or several other incompatible situations exist, **a** message will appear at the bottom of the screen, giving the user the ability to adjust to eliminate the incompatibility. When all entries have been made, and any incompatibilities eliminated, pressing of "Done" will either start the program or if the printer has been enabled, move to a new screen asking the user for a title for the printed output. Any title up to approximately 60 characters can be used. When the printout is made, the entered title plus the date and time will be shown on the heading of the output.

s.   QUIT

Locating the highlight bar on "QUIT" and pressing enter will exit CORRIDOR routine and return the user to the main fire simulator model. "QUIT" can be used anytime whether or not all entries have been made. It will erase the variables in the memory of CORRIDOR.

5.OUTPUT

Three forms of output are provided. An output appears on the computer screen as the calculations are made. If the user chooses a Lotus file, a file with the extension "wk1" and the name given by the user will be developed. This file can be read in any spread sheet compatible with Lotus format and can be used to develop graphic presentations. If the user enables the printer, a printed output such as shown in Figure 13 will be produced.

6.REPETITIVE CALCULATIONS

CORRIDOR is not capable of batch calculations. At the end of each run, however, the user **is** offered the opportunity of repeating the calculations with different variables. If the answer to this question is "yes", the main menu reappears with all of the values entered by the user except that the printer will always be disabled. The user may then adjust any values desired including enabling the printer and rerun the calculations with the adjusted variables.

7. SUMMARY

CORRIDOR gives first order estimates of the initial smoke flow wave front for many normal arrangements that will occur with a fire that exposes a corridor. Reasonable correlation appeared between the several cases that approximated type of conditions normally found in **a** room on corridor building. The correlation in the special case of the test conducted at NIST with a very narrow low door produced conditions that could not be accurately predicted by CORRIDOR. This was recognized by CORRIDOR and a warning message given. CORRIDOR also appears to over predict entrainment when the distance between the smoke interface in the door and the top of the corridor is large. Constraints are included within CORRIDOR to warn the user when this occurs.

There is an important need for further testing of fire conditions that develop from a violent fire exposing a corridor in a building. It is most important to develop these at realistic arrangements with flashover conditions and corridors of greater length than the previous experiments.

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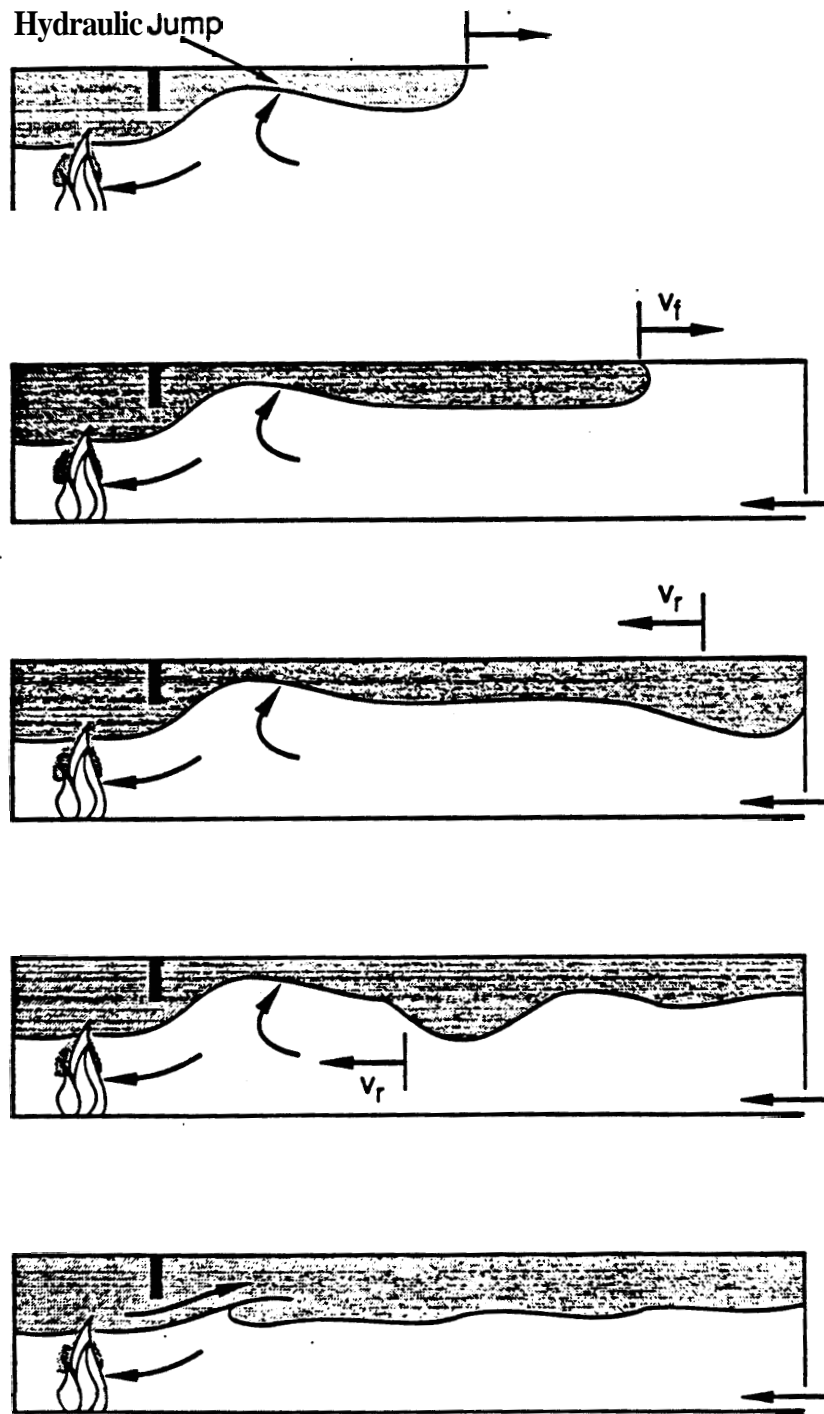
Figure 1.   Basic Features of Corridor Flow
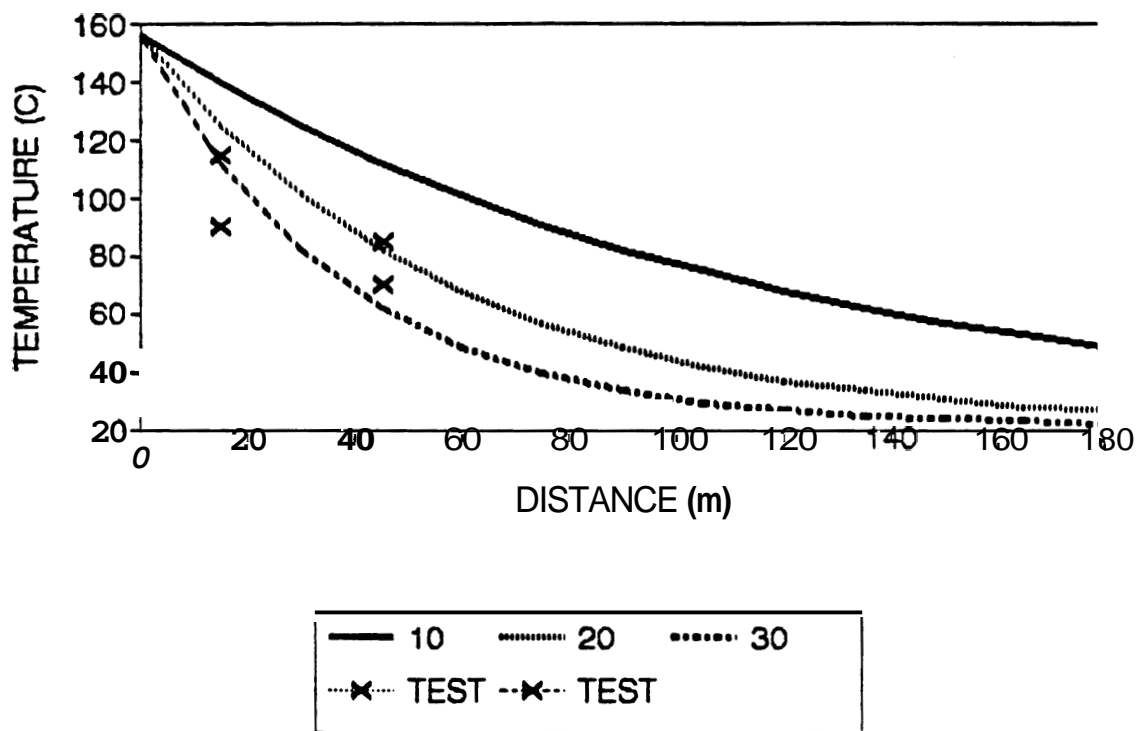
Figure 2. Tunnel test 1, 1 MW Fire, Temperature of Wave

18
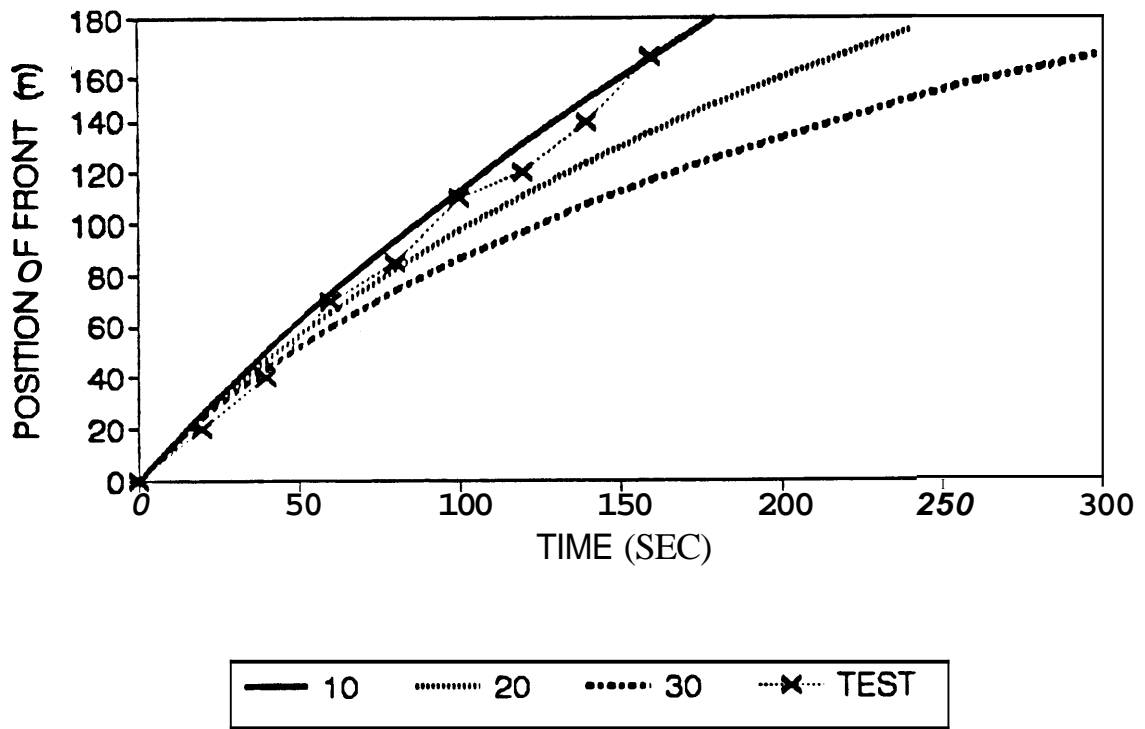
Figure 3. Tunnel test 1, 1 MW Fire, Position of Front
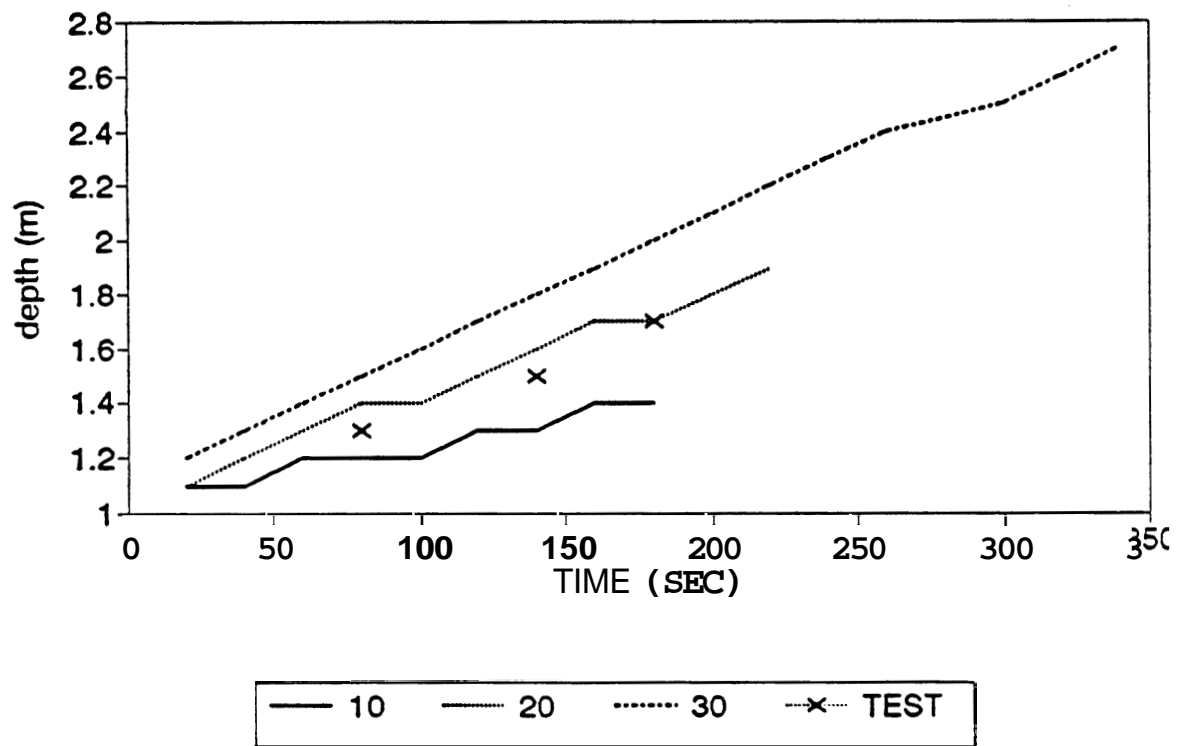
Figure 4. Tunnel test 1, 1 MW Fire, Depth of Wave
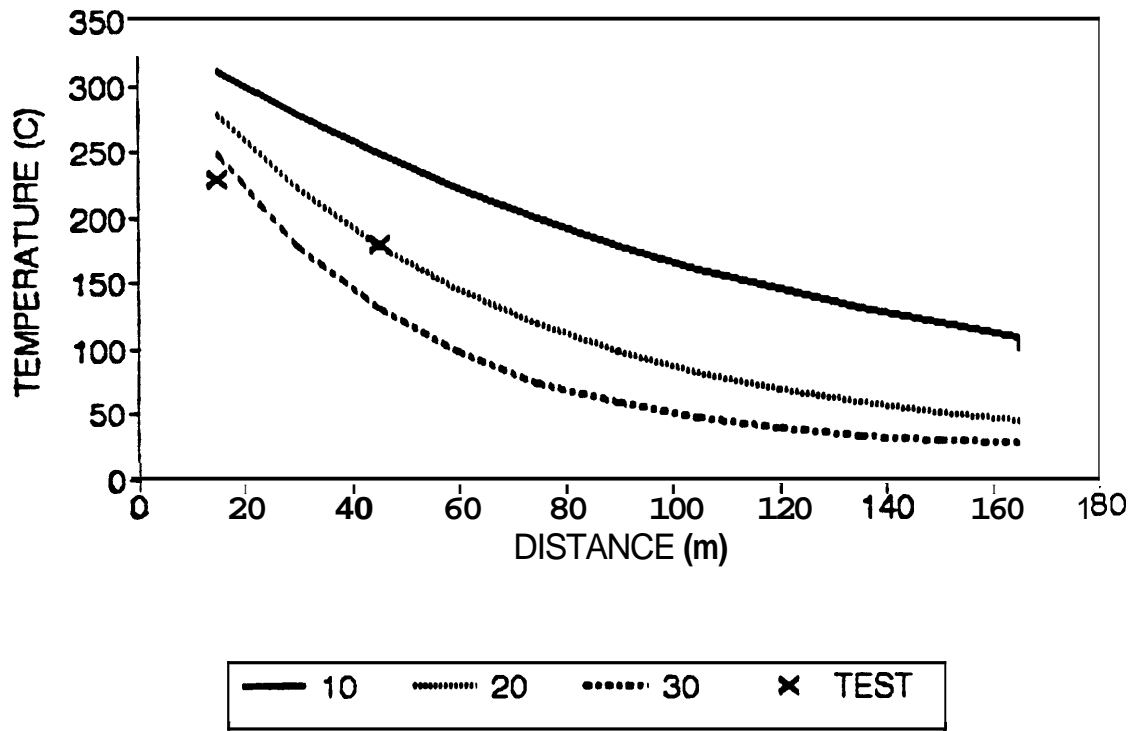
Figure 5. Tunnel test 2, 8 MW Fire, Temperature of Wave
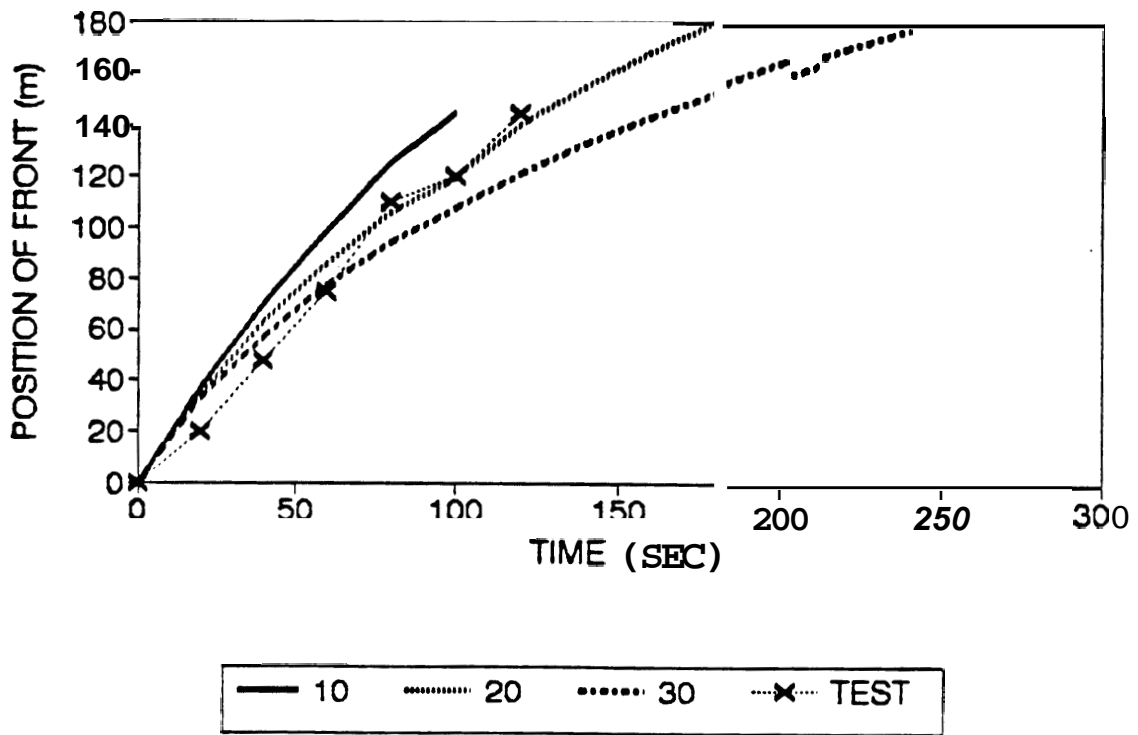
Figure 6. Tunnel test 2, 8 MW Fire, Position of Front
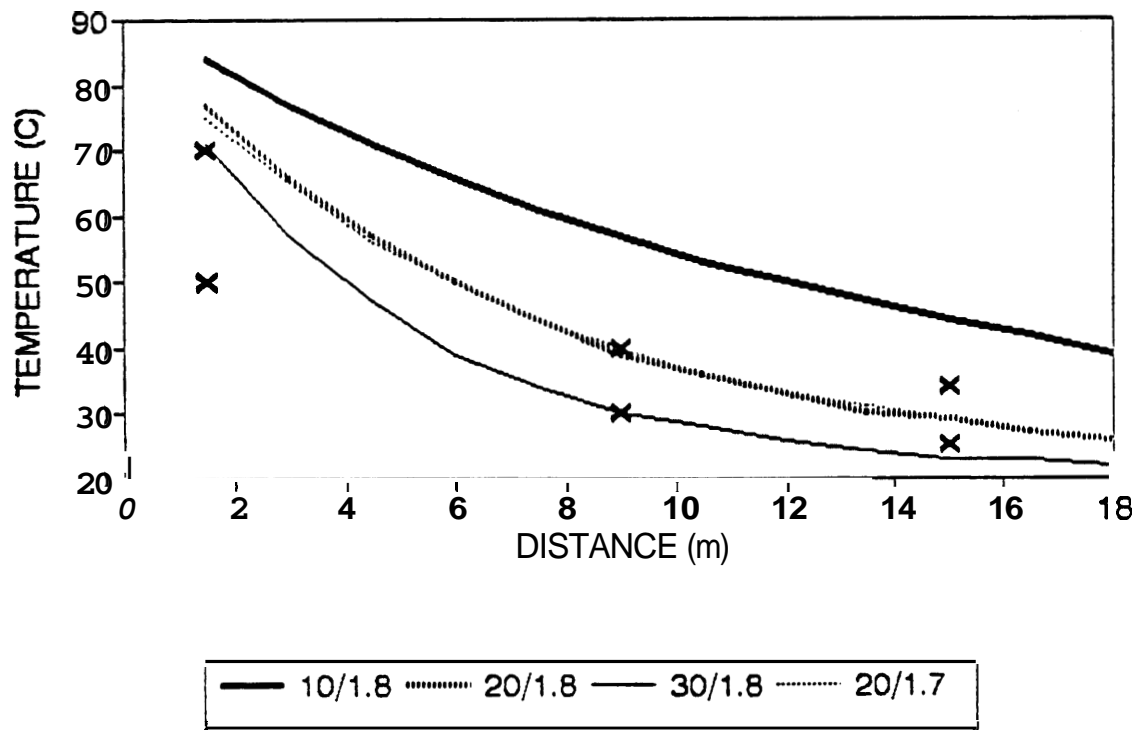
22
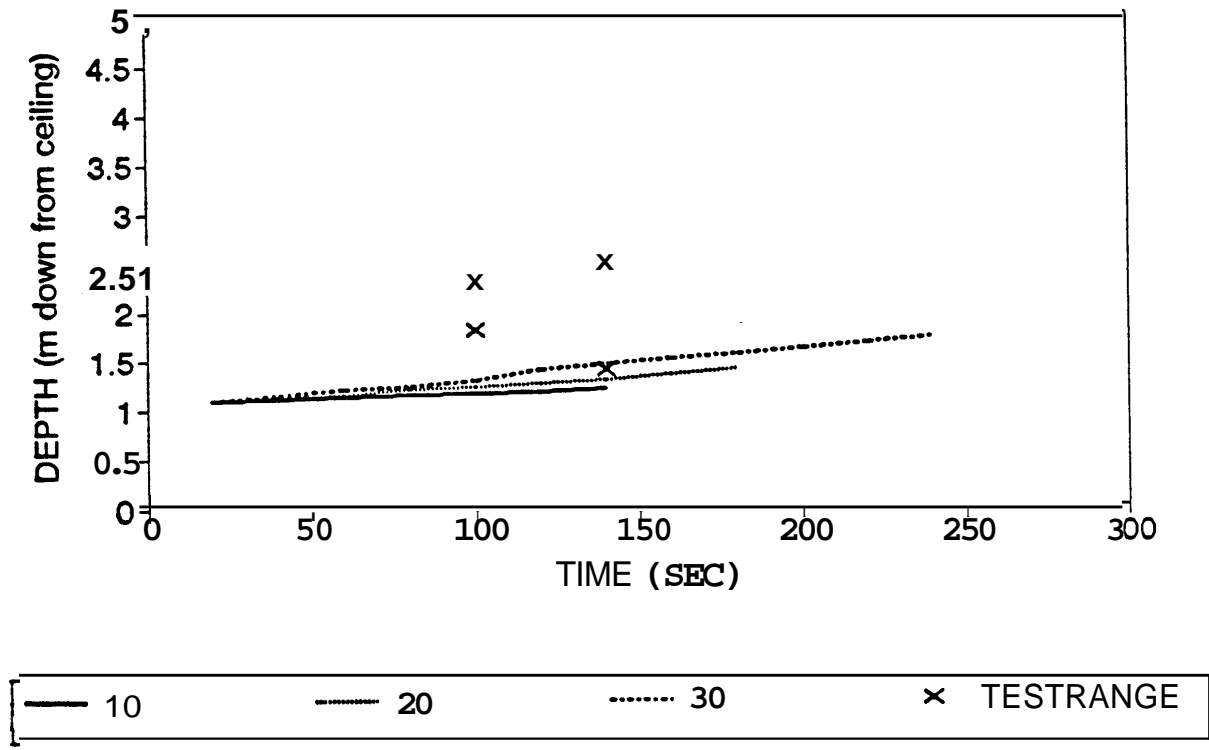
Figure 7. Tunnel test 2, 8 MW Fire, Depth of Wave

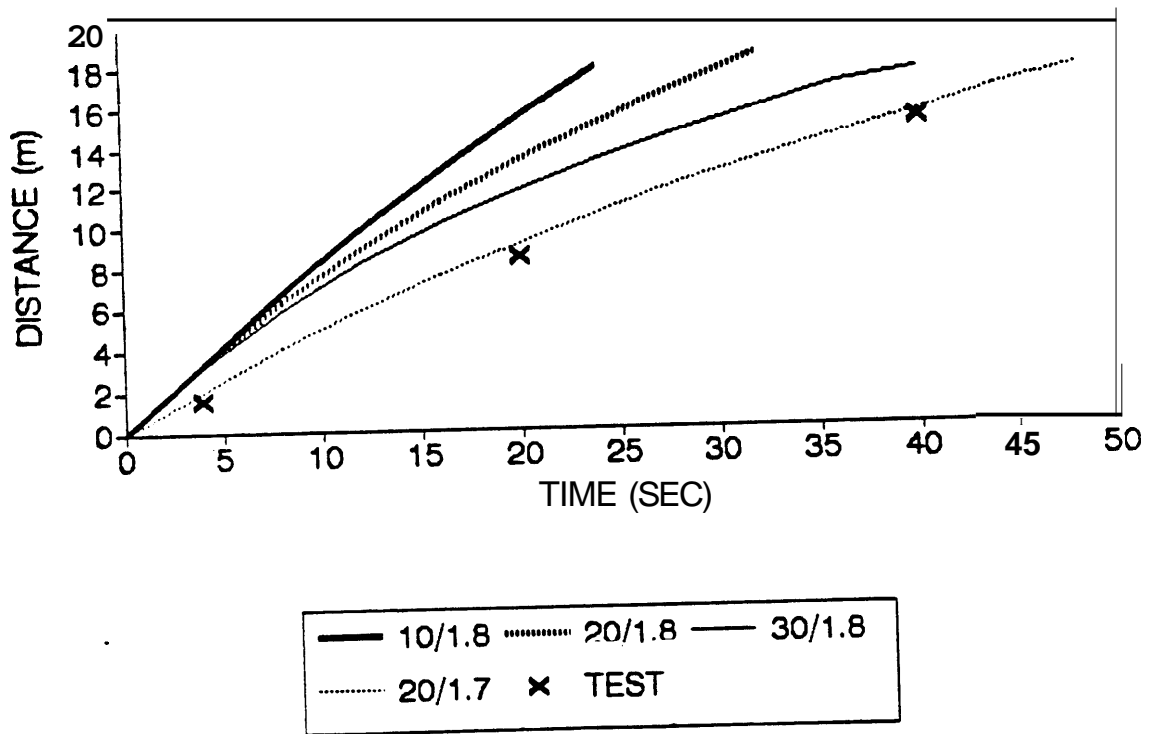23

Figure 8. Corridor test 2, 1 56kW Fire, Temperature of Wave

Figure 9. Corridor test 2 56 kW Fire, Position of Front
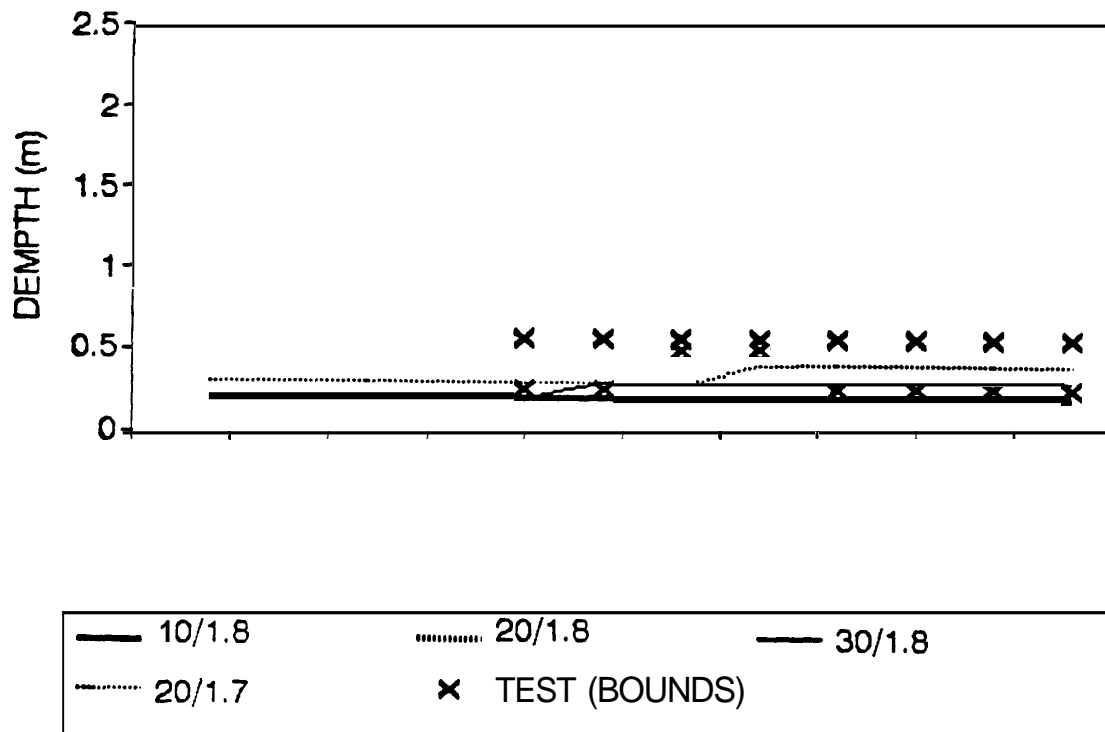
Figure 10. Corridor test 2, *56* kW MW Fire, Depth of Wave
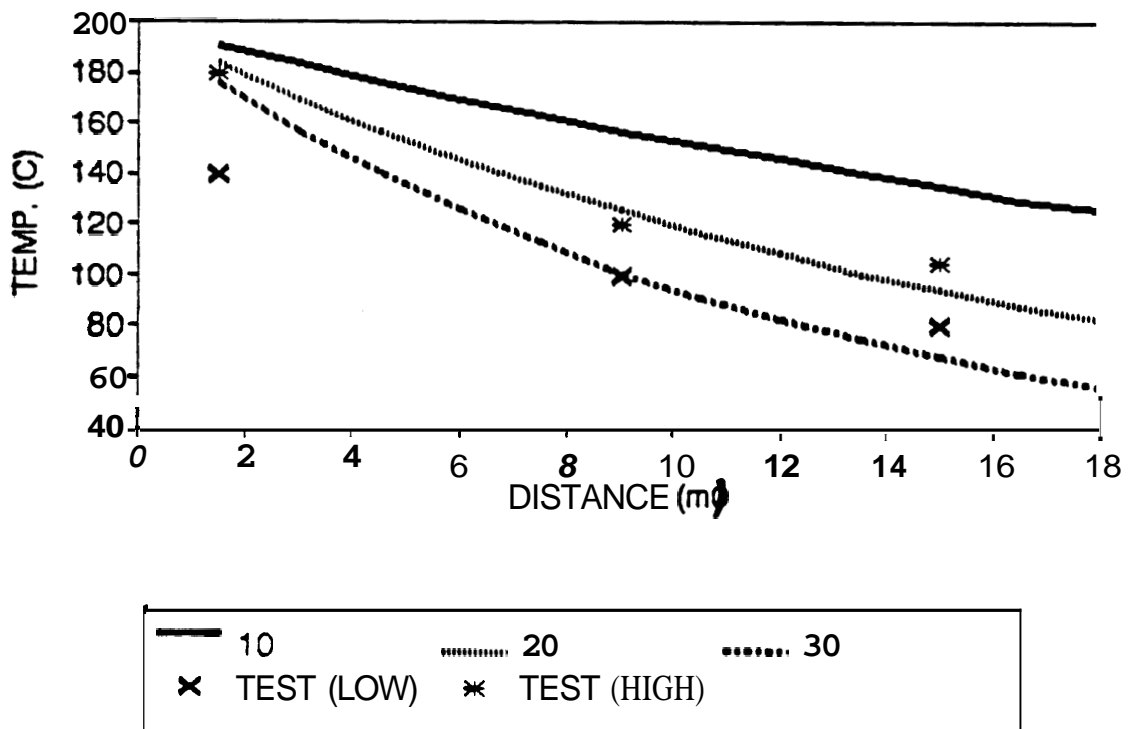
Figure 11. Corridor test 16 522 kW Fire, Temperature of Wave

27
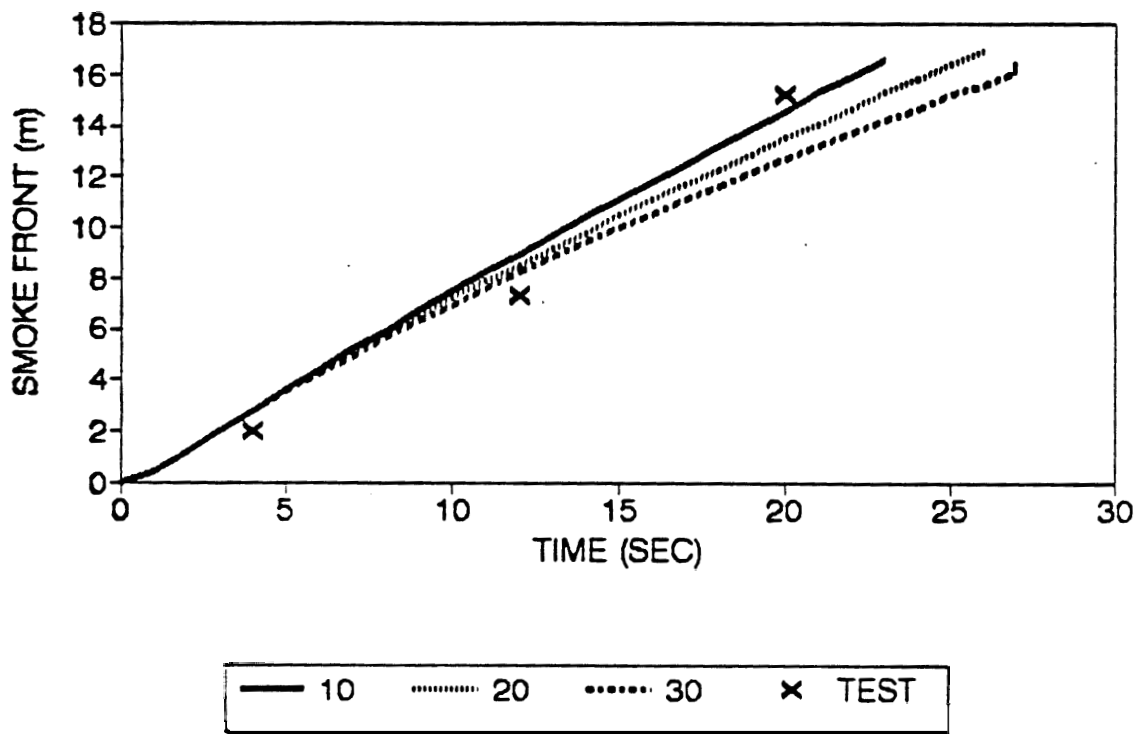
Figure 12. Corridor test 16, 522kW Fire, Position of Front

28
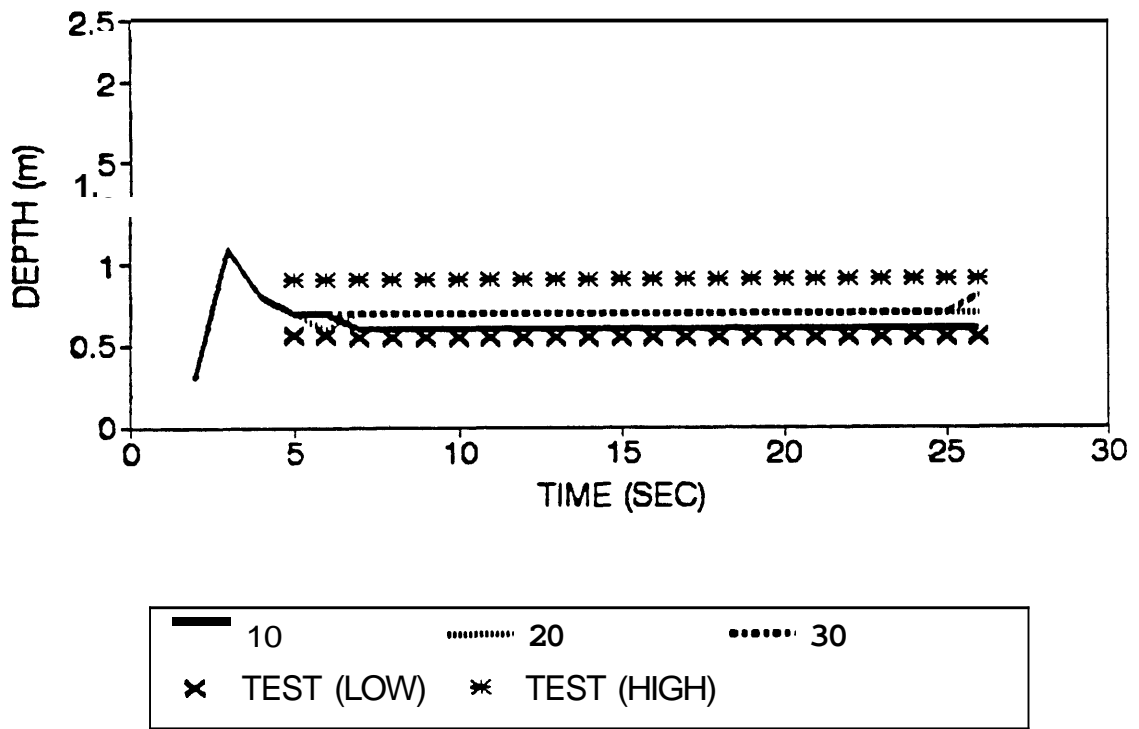
Figure 13. Corridor test 16, 522 kW Fire, Depth of Wave
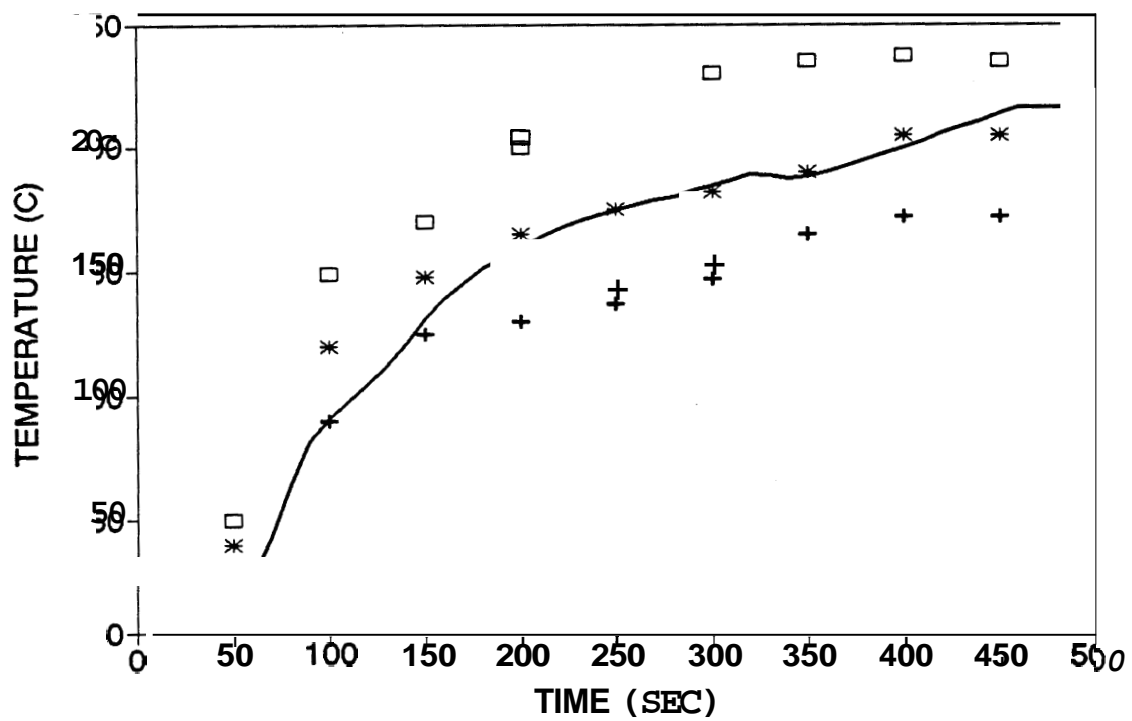
Figure 14. NIST-GSA Corridor tests, Temperature of smoke layer

30
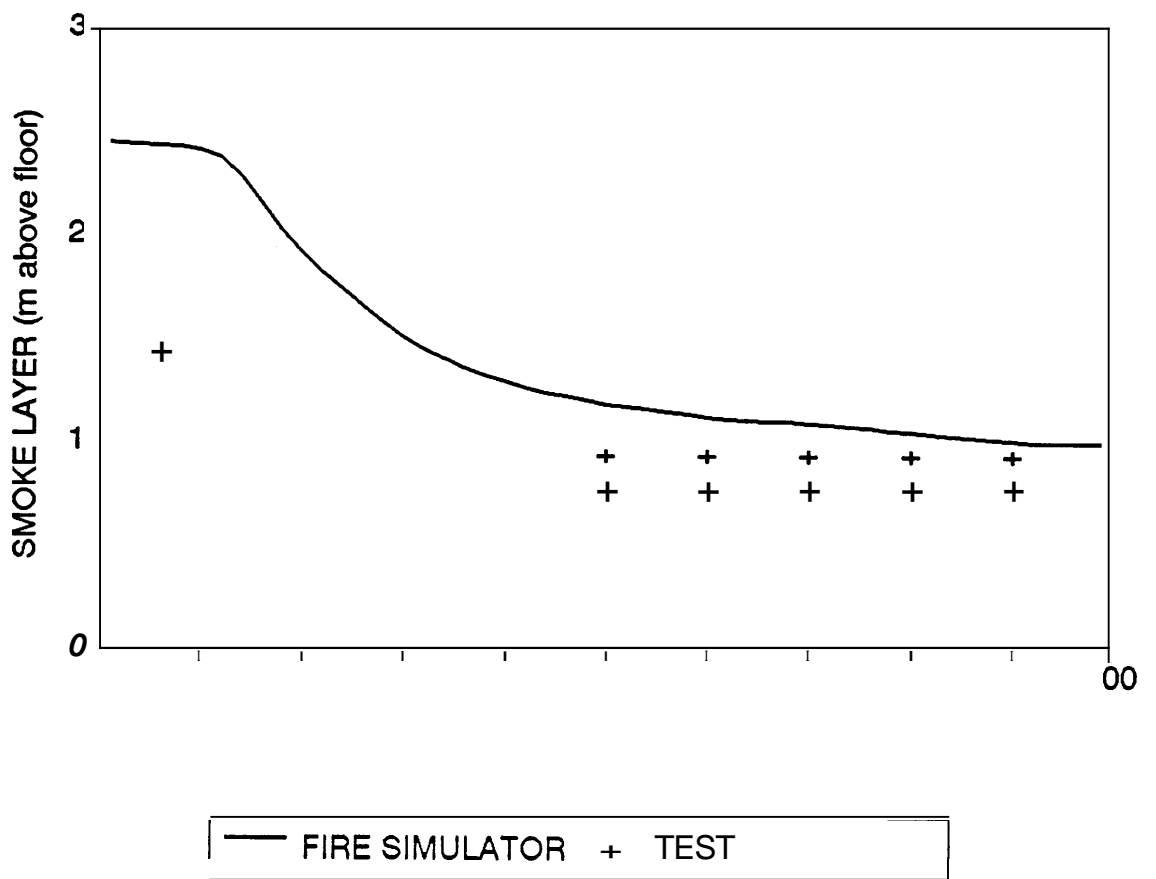
Figure 15. NIST-GSA Corridor tests, Depth of smoke layer

I. TITLE AND SUBTITLE

CORRIDOR: A Routine for Estimating the Initial Wave Front Resulting from High Temperature Fire Exposure to a Corridor

i. AUTHOR(S)

Harold E. Nelson and Scot Deal

11. ABSTRACT (A 200-WORD OR **LESS FACT ERAT SURVEY** MENTION IT HERE.) SUMMARY **OF MOS' ' SIGNIFICANT INFORMATION** IF **MEI)ES \ SIG** BIBLIOGRAPHY

A first order model and computer program implementing previously developed procedures for estimating the speed, depth, and temperature of a fire produced gravity **wave** front in a corridor have been developed. The program has been incorporated into FPETOOL and adjustments made to accommodated fires that occur in the corridor or in a room adjacent to the corridor. Comparisons to test results are presented and show reasonable correlation. **A** users' guide **is** included.

12 KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

compartment fires; computer programs; corridors; fire models; flashover; gas composition; gravity; heat loss; room fires; smoke movement